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Effect of Boron Foliar Application and Different Fruit-set Orders on Summer Squash Seed Yield and Quality

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SUMMER squash seed yield and quality can be improved by the application of boron (B) and fruit set-order, which might affect fertilization and pollination. Two field experiments were performed during the summer seasons of 2021 and 2022 to investigate the effects of foliar application of boron at levels of 0, 25, and 50 ppm for two times (after 45 and 60 days from the planting date) and different fruit-set orders on seed yield, yield components and quality in summer squash of two genotypes, Shmamy and Cope. The twelve treatments were arranged in a randomized complete block design (RCBD) with a split plot arrangement with three replicates. The results of the current study revealed that foliar application of B at 50 ppm improved seed yield components, such as fruit weight, seed weight per fruit and the number of seeds per fruit, leading to a significant increase in total seed yield in the two studied genotypes of summer squash. Also, the B application at 50 ppm increased the seed quality parameters, oil content, crude protein content and total antioxidant activity in both genotypes during the two seasons. In addition, this research revealed that fruit-set order had a significant effect on total seed yield, seed yield components and seed quality. Whereas, the fruits in 2nd and 3rd order have achieved the highest means of all seed yield components, total seed yield and seed quality parameters in both studied genotypes and during both seasons, compared to the fruits in 1st and 4th order. In light of current results, it would be recommended that applying B at 50 ppm as a foliar spray treatment and keep the fruits in second or third order to improve the total seed yield and seed quality of summer squash plants.

Keywords: *Cucurbita pepo* L., Boric acid, Fruit position, Seed weight/fruit, Seed number/fruit, crude protein, Oil content, Antioxidant.

Introduction

Squash (*Cucurbita pepo* L.) is one of the most popular vegetable crops in the world. Normally, the edible part is the fruit. However, consumption of squash seeds has recently received considerable attention in the human diet because of its high nutritional and health-protective value. Squash seeds contain several bioactive functional constituents of lipids, proteins, fibers, thiamin, niacin and micronutrients (Rubatzky and Yamaguchi, 1999, Rezig et al., 2012 and Gomes et al., 2022). It is also an extraordinarily rich source for oil, which is being used as an active ingredient in cosmetics, foods and nutraceuticals (Yadav et al., 2010). Recently, several epidemiological studies have highlighted the health benefits of squash oil against several chronic diseases, including hypertension, diabetes, low density cholesterol and several types of cancer and it also shows antibacterial and anti-inflammatory properties (Stevenson et al., 2007, Rabrenovic et al., 2014, Gutierrez, 2016 and Majid et al., 2020). These health benefits of squash oil seeds are attributed to their high content of proteins, polyunsaturated fatty acids, antioxidative phenolic compounds, carotenoids and minerals

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(Fu et al., 2006 and Rabrenovic et al., 2014). Due to these interesting benefits, raw or roasted seeds of squash are currently utilized in a wide spectrum of human diets, including cooking, baking and ground meat formulations as flavor enhancers as well as snack foods (El-Adawy & Taha, 2001 and Nawirska-Olszanska et al., 2013).

Boron (B) is an essential, immobile micronutrient needed for all stages of the plant life cycle. It is involved in several biochemical functions in plant cells, including cell division, membrane functioning, carbohydrate metabolism, protein synthesis, transportation of sugars, hormone formation, cell elongation, and development of tissue and cell wall as well as it plays a role in flower formation, pollen viability and fruit set (Marschner, 1995, Tariq and Mott, 2007, Shaaban, 2010). Furthermore, B possess many crucial effects on reproductive processes such as pollen grain germination, pollen tube growth, abortion of ovaries, flowering and seed development as well as fruit setting (Brown et al., 2002, Tahir et al., 2009), which are among the main elements attributed to yield reduction (Tariq and Mott, 2007), and B requirement during reproductive growth is significantly higher than during vegetative growth in several crop plants (Asad et al., 2003, Oyinlola, 2007). Therefore, B deficiency, especially at the flowering stage, can cause pollen viability loss as well as stamen and pistil abortion, leading to significant declines in seed set and yield (Chitralekha and Nirmala, 2000). Several previous reports observed an increase in crop productivity in response to B application. Practically, it was reported that B application had increased the total yield of wheat, rice and maize by 14, 14 and 20%, respectively, compared to control plants (Ahmed et al., 2012). Such increment in total yield of several crop species in response to B application was strongly related to enhancing the seed yield components such as grain setting and grain yield, number of grains per spike, number of spikelet per spike and 1000-grain weight in wheat (Rawashdeh and Sala, 2014) and increasing the number of formed flowers, set pods per plant, green pod and dry seed yields in broad bean plants (Abou EL-Yazied and Mady, 2012) as well as decreasing the number of the empty seeds in sunflower (Al-Amery et al., 2011) in comparison with untreated plants.

Interestingly, B application has a significant effect on the quality characters in various crop species. For instance, B has significantly increased the seed quality of soybean and sunflower seeds by increasing their amino acids, protein and oil contents (Hemantaranjan & Trivedi, 2015, Mekki, 2015). Also, Singh et al. (2007) reported that the B foliar application positively reduced the physiological disorders such as albinism, fruit malformation, and disease like grey mould, delayed fruit ripening onset and increased the quality of strawberry fruits. Despite all of these well documented positive effects of B on plant growth, development and yield, harmful effects can be induced by overdoses of B either through foliar or soil application (Cervilla et al., 2012). Abreu et al., (2005) reported the following scale: 0.0–0.2 ppm as low, 0.21–0.6 ppm medium, 0.61–1.1 ppm high, 1.2–3.0 ppm very high, and >3.0 ppm as toxic soil boron concentrations. However, the critical limits of boron vary significantly among the different plants (Brdar-Jokanović, 2020). Therefore, optimum levels of B are crucial for high crop yield. To date, very few studies have addressed the effectiveness of B on the seed yield and seed chemical compositions of squash.

Using high quality, healthy and best genetic background seeds is a prerequisite for producing higher yields and better quality in most of the horticultural crops. In cucurbits, seed production and seed quality are greatly influenced by the fruit number per plant, number of fruits per unit area, fruit shape, fruit size, population density, environmental conditions and cultural practices as well (Nerson, 2007). However, there is another factor that might strongly affect seed yield and quality in cucurbits, which is fruit position or fruit-set order. The effects of fruit-set order on seed yield and seed yield components have been investigated in some horticultural crops. Nerson (2004 and 2008) reported that fruit-set order position affected the seed yield components in melon and cucumber. Moreover, the position of the fruit on the mother plant can lead to significant changes in tomato seed quality as well as availability (Dias et al., 2006). In addition, Alan and Eser (2007) reported that seeds obtained from the lower level of the plant gave the highest values of seed weight, germination and vigor and the shortest time for seedling emergency in pepper. Moreover, seeds obtained from basal fruits were larger, germinated better and produced more vigorous seedlings than those from middle and apical fruits of okra plants (Yadav and Dhankhar, 2001). Shortly, seeds of earlier fruits from the lower part of the plant were found to be superior when compared with those from the middle and the top parts and it was suggested that the decline in seed mass towards the top of the plant could be attributed to a seasonal reduction in resource availability.

As information concerning the effects of foliar application of boron and fruit- set order on seed production and quality of summer squash is limited and incomplete, the present study was undertaken. The major goal of the present study was to investigate the effects of foliar application of boron and different fruit-set orders as well as their interaction on seed yield, seed yield components and seed quality in summer squash.

Materials and Methods

Experimental site and Plant materials

Two field experiments were performed at the Agricultural Research Farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, during the two successive summer seasons of 2021 and 2022. The plant materials used were two squash genotypes namely, Shmamy and Cope. These two genotypes are old Egyptian open-pollinated cultivars of summer squash and were collected from the farmers in Abu Elmatamir, Beheira Governorate, Egypt, which is one of the main areas in Egypt for production of summer squash seeds, in summer season of 2020.

Boron and fruit-set order treatments

Boric acid (H_3BO_3, 17% B) was obtained from El-Gomhoria company for chemicals and used as a source for boron, which was applied at three levels: 0, 25 and 50 ppm. All B treatments were given twice (after 45 and 60 days from the planting date) as foliar applications. Foliar spraying was applied in the morning (9 a.m.) using a hand sprayer. The control plants were sprayed with distilled water. The volume of applied solution was 4 liters per plot in each time. Regarding the fruit-set order, squash plants were divided into four groups as follows: 1) the 1st fruit developed was kept on the plants, 2) 1st developed fruit was removed and the 2nd fruit was kept, 3) 1st and 2nd fruits were removed and the 3rd fruit was kept and 4) 1st, 2nd and 3rd fruits were removed and the 4th fruit was kept.

Experimental design

The experiment had twelve treatments, three B levels and four fruit-set orders. The twelve treatments were applied and arranged in a randomized complete block design (RCBD) with a split plot arrangement with three replicates. The B levels were considered the main plot and the fruit–set orders were considered the sub-plots. The experimental unit area (plot) was 20 m^2 (5 m in width x 4 m in length) and contained 5 drip irrigated ridges and included 40 plants.

Cultural practices

Organic manure and calcium superphosphate (15.5% P_2O_5) were added at rates of 20 m^3/feddan and 160 kg/feddan, respectively, after plowed and harrowed of the experimental soil (85.21% sand, 3.29% clay and 11.50% silt). Seeds of both genotypes were soaked in water for 12 hrs before sowing. Later, the wetted squash seeds were directly sown in hills spaced 50 cm apart on the 5th and 8th of March in the summer seasons of 2021 and 2022, respectively. During the growing season, 300 kg of ammonium nitrate (33.5% of N) and 200 kg of potassium sulphate (48% of K_2O) were added per feddan at four doses. The other normal agricultural practices such as irrigation, fertilization, control of insects, fungi and weed control were performed according to recommendations of the Ministry of Agriculture and Land Reclamation.

Data recorded

At the end of the season, fifteen ripening squash fruits were randomly selected from each experimental plot and hand harvested. Then the fruit was weighed before manually extracted of seeds, washed and air dried. Afterwards, the following parameters were recorded:

1. Fruit weight (g).
2. Seed number per fruit.
3. Seed weight per fruit (g).
4. Seed length (cm).
5. Seed width (cm).
6. Seed thickness (cm)
7. Total seed yield (kg) per fedden.
8. Crude protein (%): it was estimated from N concentration (%) in dried seed samples by using the following formula crude protein (%) = N content (%) x conversion factor 6.25 (A.O.A.C, 1990).
9. Total antioxidant activity (%): it was measured according to Lee et al., (2003).
10. Oil content (%): it was processed with Soxhlet equipment, using petroleum ether with a boiling range of 40 – 60^{o}C as an extraction solvent over a period of 12hrs. Later, the residual solvent was evaporated in an oven at 120^{o}C for 15 min (A.O.A.C, 1990). The obtained oil was gravimetrically determined and crude oil content was calculated as a percentage.

Statistical analysis

All data were subjected to a two-way analysis of variance (ANOVA) and the significant differences among mean values of treatments were compared using Duncn's multiple range tests at 5% level of significance as implemented in *agricola*e R package (de Mendiburu and de Mendiburu, 2017). Also, a t-test was used to compare the total yield, seed yield components and seed quality parameters of two genotypes with the function t-test as implemented in *agricola* R package.

Results

The main effect of genotype

Data presented in Table 1 shows that there were significant differences between genotypes of summer squash on all studied traits in both seasons. Shmamy genotype had the highest significant means of fruit weight, seed weight per plant, number of seeds per fruit and total yield per feddan, while Cope genotype had the highest significant means of seed length, seed width, seed thickness, crude oil content, crude protein content and total antioxidant activity in both seasons of the study.

The main effect of B application

Data presented in Tables 2 and 3 clearly indicate that there were significant differences among B treatments on all studied traits in both genotypes as well as seasons. It clearly shows that the B treatment at 50 ppm significantly improved the fruit weight, seed weight per fruit, number of seeds per fruit and total yield per feddan compared to the other B treatments, 0 and 25 ppm in both genotypes and seasons, however, it significantly reduced the seed length, seed width and seed thickness in both genotypes and seasons relative to the control treatment. In addition, Tables 2 and 3, also show that the B treatments significantly affected the biochemical compositions of summer squash seeds. In both genotypes and seasons, the B treatment of 50 ppm gave the highest significant means of crude oil content, crude protein content, and total antioxidant activity. However, no significant difference was recorded between B treatments of 50 and 25 ppm in terms of crude oil content in both genotypes in the season of 2022 only as well as in crude protein content in the Cope genotype in the season of 2021 only.

The main effect of fruit-set order

Data shown in Tables 2 and 3 also show the main effect of fruit-set order on seed yield and seed yield components of summer squash. It clearly shows that there were significant differences among the fruit-set order treatments on all traits in both genotypes and seasons. The 2nd fruit order, followed by the 3rd fruit order, had achieved the maximum values of all measured traits except for the number of seeds/fruit and seed width in the season of 2021. Interestingly, there was no significant difference between the 2nd and 3rd fruit orders in most of the studied traits in both genotypes and seasons. Moreover, the fruit-set order significantly affected the seed quality parameters in Shmamy and Cope genotypes in both seasons. Tables 2 and 3 show that both 2nd and 3rd fruit orders recorded the highest significant values of crude oil content, crude protein content and total antioxidant activity compared to the 1st and 4rd fruit orders. However, no significant

TABLE 1. The effect of both squash genotypes on the seed yield, seed yield components and seed quality during the seasons of 2021 and 2022.

Trait	2021 season		2022 season	
	Shmamy	Cope	Shmamy	Cope
Fruit weight (kg)	1.79 a	1.47 b	1.85a	1.46b
Seed weight/plant (g)	32.11a	28.46b	34.11a	30.03b
Number of seeds/fruit	166.50a	134.00b	131.42a	116.89b
Seed length (cm)	1.71b	2.10a	1.83b	1.93a
Seed width (cm)	1.12b	1.27a	1.07b	1.26a
Seed thickness (cm)	0.50b	0.59a	0.45b	0.60a
Total yield (kg/feddan)	361.00a	312.98b	375.28a	329.54b
Crude oil content (%)	40.36b	43.03a	40.56b	41.64a
Crude protein (%)	33.21b	34.84a	33.46b	34.76a
Antioxidant activity (%)	13.83b	14.59a	14.18b	15.67a

Means in each horizontal row in each season followed by different letters are significantly different at p= 0.05(t-test).

TABLE 2. The effect of different B foliar application treatments and fruit-set orders as well as their interaction effects on seed yield and seed yield components in the 2021 growing season.

Trait	Fruit No.	Shmamy				Cope			
		Boron treatments				Boron treatments			
		0	25	50	Mean	0	25	50	Mean
Fruit weight (kg)	1	1.32d	1.45d	1.54cd	1.44c	1.20c	1.19c	1.94a	1.44ab
	2	1.97ab	2.19a	2.16a	2.11a	1.06c	1.82a	1.92a	1.60a
	3	1.68bcd	2.00ab	2.19a	1.96a	1.31bc	1.90a	1.31bc	1.51a
	4	1.64bcd	1.48d	1.90abc	1.67b	1.11c	1.52b	1.34bc	1.32b
	Mean	1.65b	1.78b	1.95a		1.17b	1.60a	1.62a	
Seed weight/ plant (g)	1	23.43cd	34.75ab	30.63bc	29.60b	21.77d	26.53cd	29.57bcd	25.95b
	2	30.30bc	39.23a	38.97a	36.17a	24.57cd	31.63abc	37.53a	31.24a
	3	30.63bc	36.63ab	38.05a	35.10a	25.23cd	29.87bcd	35.77ab	30.28a
	4	22.10d	26.17cd	34.47ab	27.58b	22.27d	25.77cd	31.05abc	26.36b
	Mean	26.62b	34.20a	35.53a		23.64c	28.45b	33.48a	
Number of seeds/fruit	1	95.00d	155.33b	135.67b	135.33b	68.00d	74.67d	127.00bc	89.88b
	2	130.67c	176.33ab	195.00a	167.33a	86.00d	147.33ab	151.33ab	128.22a
	3	154.00b	176.67ab	168.67b	166.44a	68.00d	162.67a	158.33a	129.67a
	4	71.67e	114.33cd	164.67b	116.80c	68.00d	111.33c	145.33ab	108.22ab
	Mean	112.83c	155.66b	171.00a		102.50c	124.00b	145.50a	
Seed length (cm)	1	1.60efg	1.50efgh	1.40gh	1.5b	2.27abc	1.97ef	1.90f	2.04bc
	2	2.27a	2.00abc	1.70def	1.99a	2.33ab	2.13bcde	2.20abcd	2.22a
	3	2.13ab	1.93bcd	1.53efgh	1.87a	2.37a	2.10cdef	2.00def	2.16ab
	4	1.73cde	1.30h	1.43fgh	1.49b	2.13bcde	1.90f	1.90f	1.98c
	Mean	1.93a	1.68b	1.52c		2.28a	2.03b	2.00b	
Seed width (cm)	1	1.03cde	1.00de	0.98de	1.01b	1.40b	1.20de	1.11ef	1.24c
	2	1.27a	1.27a	1.23ab	1.26a	1.53a	1.20de	1.26cd	1.33b
	3	1.30a	1.23ab	1.13bc	1.22a	1.53a	1.33bc	1.33bc	1.40a
	4	1.1cd	0.98e	0.96e	1.01b	1.27cd	1.07f	1.03f	1.12d
	Mean	1.18a	1.12b	1.08b		1.43a	1.2b	1.18b	
Seed thickness (cm)	1	0.54ab	0.45de	0.5abcd	0.50a	0.63a	0.59ab	0.52bc	0.58ab
	2	0.53ab	0.52abc	0.51abc	0.52a	0.64a	0.61ab	0.62a	0.62a
	3	0.54a	0.53ab	0.49bcd	0.52a	0.63a	0.61ab	0.55abc	0.60a
	4	0.52abc	0.41e	0.47cd	0.47b	0.63a	0.50c	0.49c	0.54b
	Mean	0.53a	0.48b	0.49b		0.63a	0.58b	0.55b	
Total yield (Kg)	1	257.67e	347.67cde	328.67cde	311.33b	264.90c	309.60abc	300.60abc	291.70b
	2	317.67de	441.67ab	519.67a	426.33a	308.70abc	347.40a	328.50ab	329.00a
	3	319.67de	419.00bc	414.33bc	384.31ab	315.00abc	355.50a	316.50abc	328.20a
	4	261.33e	361.33bcd	343.33cde	322.00b	279.60bc	318.90abc	310.50abc	303.00a
	Mean	289.08b	392.42a	401.50a		292.05b	314.02ab	332.85a	
Oil content (%)	1	36.00cd	36.33cd	39.00c	37.11b	38.33ef	42.33cd	40.67de	40.44b
	2	43.33ab	43.33ab	45.67a	44.11a	45.00bc	46.00ab	48.33a	46.44a
	3	42.33b	43.67ab	43.67ab	43.22a	46.00ab	44.33bc	48.00a	46.11a
	4	37.33cd	45.33d	38.33cd	37.00b	37.67f	39.33ef	40.33def	39.11b
	Mean	39.75b	39.67b	41.67a		41.75b	43.00b	44.33a	
Crud protein (%)	1	29.02f	30.52ef	36.25ab	31.93b	30.58e	35.92abc	35.16abc	33.89b
	2	32.86cd	33.86bcd	36.64a	34.45a	36.02abc	34.5bcd	37.06ab	35.86a
	3	33.95bcd	34.49abc	36.08ab	34.84a	34.88abc	36.45ab	37.15a	36.16a
	4	29.93ef	31.67de	33.32cd	31.64b	34.68abc	32.16de	33.49cd	33.44b
	Mean	31.44c	32.63b	35.57a		34.04b	34.76ab	35.72a	
Antioxidant (%)	1	11.90cd	11.21d	15.54ab	12.88b	11.97c	13.98b	14.75b	13.56b
	2	14.32abc	14.72ab	16.38a	15.14a	14.70b	15.05b	16.59a	15.49a
	3	13.91abc	13.80bc	16.39a	14.69a	14.79b	15.05b	16.72a	15.48a
	4	11.33d	11.86cd	14.61ab	12.60b	12.54c	14.65b	14.33b	13.84b
	Mean	12.86b	12.89b	15.72a		13.50c	14.68b	15.60a	

Mean values of boron and fruit number treatments in each row and column, respectively, followed by the same letters are not significantly different at 5% level, according to Duncan's multiple range test

TABLE 3. The effect of different B foliar application treatments and fruit- set orders as well as their interaction effects on seed yield and seed yield components in the 2022 growing season.

Trait	Fruit No.	Shmamy				Cope			
		Boron treatments				Boron treatments			
		0	25	50	Mean	0	25	50	Mean
Fruit weight (kg)	1	1.25g	1.52ef	1.61e	1.46d	1.09e	1.14de	1.45c	1.23c
	2	2.04c	2.33a	2.29a	2.22a	1.24d	1.89ab	1.92a	1.68a
	3	1.78d	2.17b	2.27ab	2.07b	1.09e	1.78b	1.97a	1.61b
	4	1.41f	1.55e	1.97c	1.64c	1.07e	1.40c	1.40c	1.29c
	Mean	1.62c	1.89b	2.04a		1.12c	1.55b	1.69a	
Seed weight/ plant (g)	1	24.43g	36.08cd	34.97d	31.83c	20.77g	28.20d	34.23b	27.73b
	2	32.3ef	42.23ab	43.97a	39.50a	25.57e	33.97bc	38.87a	32.80a
	3	31.63ef	37.63c	40.38b	36.55b	25.90e	32.20bc	38.10a	32.07a
	4	21.43h	30.50f	33.80de	28.58d	23.03f	27.43de	32.05c	27.51b
	Mean	27.45c	36.61b	38.28a		23.82c	30.45b	35.81a	
Number of seeds/fruits	1	113.67h	164.67de	168.33cd	148.89c	102.00f	112.00ef	157.67c	123.89c
	2	160.00e	202.33a	204.33a	188.89a	119.67e	186.00a	186.67a	164.11a
	3	143.33f	187.00b	188.00b	172.78b	103.33f	191.33a	190.33a	161.67a
	4	94.33i	137.00g	174.00c	135.11d	103.00f	136.67d	174.00b	137.89b
	Mean	127.83c	172.75b	183.67a		107c	156.5b	177.17a	
Seed length (cm)	1	1.67ef	1.47fg	1.40g	1.51b	1.97bcd	1.70e	1.80cde	1.82b
	2	2.43a	1.97cd	1.93cde	2.11a	2.23a	2.00bc	2.00bc	2.08a
	3	2.27ab	2.03bc	1.90cde	2.07a	2.17ab	1.97bcd	1.90cde	2.01a
	4	1.73def	1.70def	1.50fg	1.64b	1.93cd	1.77de	1.70e	1.80b
	Mean	2.03a	1.79b	1.68b		2.08a	1.86b	1.85b	
Seed width (cm)	1	1.00cde	0.97de	0.96de	0.98 b	1.21def	1.10ef	1.17def	1.16b
	2	1.27a	1.20ab	1.10bcd	1.19a	1.43ab	1.40abc	1.27bcde	1.37a
	3	1.27a	1.13abc	1.10bcd	1.17a	1.49a	1.33abcd	1.23cdef	1.35a
	4	0.96de	0.97de	0.92e	0.95b	1.27bcde	1.13ef	1.06f	1.15b
	Mean	1.12a	1.07ab	1.02b		1.35a	1.24b	1.18b	
Seed thickness (cm)	1	0.45b	0.44bc	0.4cd	0.43b	0.67a	0.54de	0.52e	0.57b
	2	0.52a	0.51a	0.44bc	0.49a	0.70a	0.65ab	0.59cd	0.65a
	3	0.52a	0.51a	0.4cd	0.48a	0.70a	0.6bc	0.60bc	0.63a
	4	0.44bc	0.43bc	0.37d	0.41b	0.67a	0.52e	0.50e	0.56b
	Mean	0.48a	0.47a	0.40b		0.68a	0.58b	0.55c	
Total yield (Kg)	1	271.00f	364.33cd	343.00cde	326.11c	269.23f	333.93bc	349.60ab	317.59b
	2	327.67e	454.00b	529.00a	436.89a	312.43de	361.83a	358.40a	344.22a
	3	335.67de	439.33b	437.67b	404.22b	324.6cd	333.17bcd	362.17a	339.98a
	4	271.33f	371.33c	359.00cde	333.89c	294.43e	317.17cd	337.5bc	316.37b
	Mean	301.42b	407.25a	417.17a		300.18c	336.53b	351.92a	
Oil content (%)	1	34.67f	38.00de	39.67cd	37.44b	37.33b	38.00b	42.33a	39.22b
	2	41.33bc	46.00a	44.67a	44.00a	44.00a	45.00a	45.33a	44.78a
	3	42.33b	45.00a	44.33a	43.89a	45.00a	44.67a	44.00a	44.56a
	4	34.67f	36.67e	39.33d	36.89b	36.67b	38.00b	39.33b	38.00b
	Mean	38.25b	41.42a	42.00a		40.75b	41.42ab	42.75a	
Crud protein (%)	1	28.02d	34.58bc	33.85c	32.15b	30.25e	34.26c	36.16b	33.56b
	2	33.86c	35.31abc	36.86ab	35.34a	33.88c	35.79b	38.49a	36.05a
	3	34.95bc	33.42c	37.49a	35.28a	34.35c	35.50b	38.06a	35.97a
	4	29.26d	29.65d	34.34c	31.08b	32.01d	32.83d	35.49b	33.44b
	Mean	31.52c	33.24b	35.63a		32.62c	34.59b	37.05a	
Antioxidant (%)	1	12.49e	14.04d	17.34abc	14.62b	12.63d	12.98cd	14.42b	13.34b
	2	16.52bc	16.12bc	18.51a	17.05a	14.04bc	14.72b	16.72a	15.16a
	3	15.93c	16.37bc	17.52ab	16.61a	13.79bc	14.05bc	16.26a	14.70a
	4	13.99d	13.13de	16.07bc	14.40b	12.54d	13.99bc	13.99bc	13.51b
	Mean	14.73b	14.92b	17.36a		13.25c	13.93b	15.35a	

Mean values of boron and fruit number treatments in each row and column, respectively, followed by the same letters are not significantly different at 5% level, according to Duncan's multiple range test.

difference was observed between the 2nd and 3rd fruit orders in terms of seed quality parameters in both genotypes and seasons.

The interaction effect of B application and fruit-set order

Data presented in Tables 2 and 3 show the interaction effects between B treatments and fruit-set order on total seed yield and seed yield components as well as seed quality parameters of summer squash. It generally shows that the 2nd and 3rd fruit orders on B treated squash plants at 50 ppm had the highest mean values of fruit weight, seed weight per fruit, number of seeds per fruit, total seed yield per feddan (except for the Cope genotype in the season of 2021), crude oil content, crude protein content and total antioxidant activity in both genotypes and seasons. However, the 2nd and 3rd fruit orders on B-untreated plants recorded the highest mean values of seed length, seed width and seed thickness.

Discussion

Seed quality is one of the most important inputs for enhancing the productivity of vegetable crops. As a result, the current study was designed to investigate the effect of B element foliar application and fruit-set order on total seed yield, seed yield components and seed quality in summer squash. The obtained data in this research generally indicated that foliar application of B significantly improved the seed yield, seed yield components and seed quality in both genotypes compared to untreated plants, as shown in Tables 2 and 3. In the Shmamy genotype, the application treatments of B at 25 and 50 ppm significantly increased the total seed yield per feddan by 35.75 and 38.89% in the first season of 2021 as well as by 35.11 and 38.40% in the second season of 2022, respectively, compared to control plants. In the same regard, a moderate increase in total yield per feddan (13.97 and 7.52% in the first season of 2021 as well as 17.24 and 12.10% in the second season of 2022) was observed in the Cope genotype by application of B at 25 and 50 ppm, respectively, compared to control plants. In this respect, the exogenous application of B increased the total seed yields of wheat, rice and maize by 14, 14 and 20%, respectively, (Ahmed et al., 2012). Also, the results of Mumivand et al., (2021) suggested that the foliar application of B can be considered a suitable method to increase the quantity and quality of the crop and seed yields of *S. khuzistanica.* In fact, the increase in seed yield of summer squash seeds by B application in the current study may be due to the increase in the seed yield component traits, e.g. fruit weight, seed weight per fruit and number of seeds per fruit (Table 2). In accordance with this result, previous studies have reported that B application increased the seed yield components in broad bean (e.g., number of formed flowers, set pods per plant, green pod and dry seed yields) and wheat (e.g., grain set, number of grains per spike, number of spikelets per spike and thousand-grain weight), leading to a significant improvement in total seed yield. This significant improvement in total seed yield and seed yield components in response to B application might be attributed to the critical role of B in increasing the germination of pollen grains, growth of pollen tube and seed development as well as reducing ovaries abortion, which are highly correlated to total yield (Brown et al., 2002, Tariq and Mott, 2007, Tahir et al., 2009).

In addition, the high seed yield of B treated plants might be attributed to the stimulatory effect of B on chlorophyll content (Thurzo et al., 2010). In the current research, B-treated plants had a higher chlorophyll content than un-treated plants (data not shown). Therefore, the increase in total seed yield here might be attributed to the increased photosynthetic pigments, as a result, the capacity and efficiency of photosynthesis process increased which in turn improved crop yield and quality. In harmony with this result, Ali et al., (2017) reported that the B application improved the total leaf chlorophyll content.

Squash seed consumption is very common and popular in several cultures as snacks or in other products such as bakery products and is a rich source for oil due to its higher nutritional and health-protective values as antibacterial and anti-inflammatory properties (Rabrenovic et al., 2014, Gutierrez*.,* 2016). Consequently, it will be interesting to increase these bioactive functional compounds and oil content in the seeds of summer squash. In the current study, B application at 50 ppm significantly improved the seed quality traits, crude oil content, crude protein content and total antioxidant activity in both genotypes and seasons (Tables 2 and 3). In harmony with our results, Mumivand et al. (2021) reported that foliar application of B had a significant effect on the essential oil content and yield of *S. khuzistanica.* Also, Hemantaranjan and Trivedi, (2015) and Mekki, (2016) recorded an increase in amino acids, protein and oil contents in seeds of soybean and sunflower in response to B application. The promotive effect of B in enhancing these compounds in seeds of summer squash might be referred to the vital role of B in several biochemical processes such as nitrogen metabolism, carbohydrate metabolism, amino acid and protein synthesis and sugar translocation (Cakmak et al., 1995, Cakmak and Römheld, 1997), which are strongly related to the seed biochemical compositions.

Surprisingly, the B application, particularly at 50 ppm, led to a significant decrease in seed length, width and thickness in both genotypes. Nevertheless, this decline could be attributed to the reduction in nutrient availability due to the high number of set seeds in fruits as a consequence of B application (Tables 2 and 3), thus, the competition among seeds was probably higher. Also, B application generally improved the total seed yield, yield components and quality parameters compared to untreated plants, however, this improvement is dose-independent and consequently not necessarily significant (Tables 2 and 3). In the shade of these results, it would be recommended to spray the summer squash plants by B at 50 ppm in order to achieve the maximum means of total seed yield, yield components and seed quality.

Data obtained from the current study also shows the existence of variation in total seed yield and seed yield components among summer squash seeds produced from different fruit-set orders in both genotypes and seasons (Tables 2 and 3). In the current study, the 2nd and 3rd fruit orders have achieved the highest significant means, compared to the 1st and 4th fruit orders, for most of seed yield components in both genotypes and seasons, leading to the highest significant improvement in total seed yield. This finding partially contradicts results from studies on melon and cucumber (Nerson, 2004 and 2008), which found that the fruit weight and seed yield per fruit decreased with increasing fruit-set order. Also, Alan and Eser (2007) reported that the fruit weight and seed yield gradually decreased with fructification, from the first to the third layer in pepper. Nevertheless, the 4th fruit order in the current study achieved lower means of seed yield components and total seed yield than the 2nd and 3rd fruit orders, which is in harmony with those previously mentioned. Generally, seeds of middle fruits (2nd and 3rd) were found to be superior to those from the lower fruit (1st) and the top fruit (4th) and it is suggested that the decline in seed yield towards the top of the plant could be attributed to a seasonal reduction in resource availability (Nerson, 2004 and 2008, Alan and Easer, 2007), while the decline in seed yield of earlier fruits might be attributed to uncompleted vegetative growth or due to pollen grain inactivity in the early stage of plant growth.

Fruit-set order also had a significant effect on seed quality parameters, crude oil content, crude protein content and total antioxidant activity in both genotypes and seasons, whereas, the 2nd and 3rd fruit orders obtained higher means than the 1st and 4th fruit orders (Tables 2 and 3). In the same context, Alan and Easer (2007) reported that the seeds extracted from the fruits of the first layer had a higher germination and vigour as well as a lower mean germination time than those from the other layers. Also, fruit-set order had a significant effect on the percentage of seed germination (Nerson, 2004). Therefore, fruit-set order should be taken into account by the hybrid seed production companies to ensure a high germination and post germination parameters, especially in vegetable production, as most of the used seeds are hybrids and expensive.

The present study clearly revealed that B application at 50 ppm gave the highest significant means of the total seed yield, seed yield components and seed quality traits and it also revealed that there was no significant difference between the 2nd and 3rd fruit orders in terms of the aforementioned traits (Tables 2 and 3). Consequently, it is recommended to apply 50 ppm of B to summer squash plants and to keep the 2nd or 3rd fruit orders on the treated plants, as they achieved not only the maximum values of total seed yield but also seed yield parameters and seed quality traits.

Conclusion

The results revealed that foliar application with boron at 50 ppm significantly improved yield component traits such as fruit weight, number of seeds per fruit and seed weight per plant as compared with the control treatment, leading to a significant increase in the total seed yield. In addition, keeping the 2nd fruit order on summer squash plants significantly improved the total seed yield and its quality parameters, such as crude oil content, crude protein content and total antioxidant activity. As a result, spraying summer squash plants with boron at 50 ppm and keeping the second or third fruit order would be recommended to increase total seed yield and seed quality.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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تأثير الرش الورقي بالبورن وترتيب الثمار على محصول وجــودة بذور الكوسة

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يمكن تحسين محصول وجودة بذور الكوسة عن طريق الرش بالبورون وترتيب الثمار على النبات والتي ربما تؤثر على الخصوبة والتلقيح. ولذلك تم إجراء تجربة حقلية في موسمين متتاليين خلال الموسم الصيفي لعامي ٢٠٢١ و٢٠٢٢ م لدراسة تأثير الرش الورقي بعنصر البورون وترتيب الثمرة على النبات واستجابة محصول البذور ومكونات المحصول وجودة البذور في الكوسة لهذه المعاملات. أوضحت النتائج المتحصل عليها أن الرش الورقي بالبورون بتركيز ٥٠ جزء فى المليون قد أدى إلى تحسن مكونات محصول البذور من حيث وزن الثمرة ووزن البذور بالثمرة الواحدة وكذلك عدد البذور فى الثمرة؛ مما أدى فى النهاية إلى حدوث زيادة معنوية في المحصول الكلي للبذور في كل من طرازي الكوسة الشمامي والكوبي. أيضاً أدى الرش بالبورون بتركيز ٥٠ جزء فى المليون إلى حدوث زيادة في صفات جودة البذور مثل: محتوى الزيت والبروتين الخام ومضادات الأكسدة في الطرازين تحت الدراسة وفي موسمي الزراعة. أظهرت الدراسة أيضا أن رتبة أو ترتيب الثمرة على النبات كان لها تأثيرمعنوي على المحصول الكلي للبذور ومكونات محصول البذور وجودة البذور الناتجة؛ حيث أن الثمرة الثانية والثالثة في الترتيب على النبات قد أعطت أعلى قيم للمتوسطات لجميع مكونات محصول البذور مثل: المحصول الكلي للبذور وصفات جودة البذور في الطرازين وفي كلا الموسمين مقارنة بالثمرة الأولى والرابعة في الترتيب على النبات. وفي ضوء هذه النتائج، يمكن التوصية بالرش الورقي بعنصر البورون بتركيز ٥٠ جزء فى المليون مع الاحتفاظ بالثمرة الثانية أو الثالثة في الترتيب على النبات وذلك لزيادة محصول وجودة بذورالكوسة الناتجة.